14p

EXTENSION OF THE MEASURED EXPERIENCE OF HUMAN IMPACT LOADS

By

Gerard J. Pesman[*]

Harris F. Scherer, Jr.[**]

INTRODUCTION

At the present time, there is associated with ballistic reentry of spacecraft an impact landing that cannot be considered the acme of comfort. Further, this landing occurs as the final event in a long series of physiological stresses. This is the case on an orbital flight where these physiological stresses include: a long wait on the launching pad, lying in essentially the supine position; the acceleration, vibration, and noise of the launch; hours, days, or even weeks of weightlessness in a crowded vehicle in which exercise will be difficult; the acceleration and heat of reentry; the parachute opening shocks; and finally the landing, which, if not attenuated, can reach 40g even in a water landing. The astronauts are expected to endure these many stresses and yet be able to make a full-bodied, intelligent survival attempt; or to be fully able to assist in the search and recovery procedure.

The landings can be made less strenuous, but the attending weight and space penalties are so severe that every means available must be used to reduce the impact attenuation system weight to a minimum. To obtain this weight reduction, however, requires that the astronauts be subjected to stress near the maximum acceptable level, and yet not be overstressed. Such optimized designs are impossible, however, unless reasonably complete data are available on how impacts of various magnitudes, directions, rise-times (onset), and durations will affect humans supported or restrained in various ways.

The investigation of human response to impact is not new. A survey of the literature such as the studies conducted by Eiband shows, however, that only four of the six major directions with respect to the human body

---

[*] Head, Acceleration Section, Environmental Physiology Branch, Crew Systems Division, NASA Manned Spacecraft Center, Houston, Texas

[**] Aerospace Technologist, NASA Manned Spacecraft Center, Houston, Texas

[redacted]

have been studied. Of these four directions, only the forward acting forces (eyeballs in or $+G_x$) (fig. 1), the backward acting forces (eyeballs out or $-G_x$), and the headward acting forces (eyeballs down or $+G_z$) have been investigated to a degree such that tolerance limits may be set. The investigation of tailward acting forces (eyeballs up or $-G_z$) was limited to a series of ejections in the 8 to 11g range conducted during the development of the downward ejection seat. No reports of the experimental exposure of humans to purely lateral impact could be found although there are some animal data. Thus, there are not enough data available for a thorough study of the landing problem. There are, however, references to fatal accidents in which the great vessels in the chest were torn or ruptured. It is also implied that these injuries are the result of either lateral or tailward acting forces. Thus, there was considerable anxiety among those responsible for the safety of test subjects and the occupants of spacecraft about the possible hazard associated with exposure to lateral or tailward acting forces.

DESCRIPTION OF IMPACT PROGRAM

After consideration of the entire problem, it was decided that an impact program to obtain additional impact data should be conducted and this program should be divided into three separate phases. Because of the implied hazard associated with lateral and tailward acting forces (fig. 2), and because a better definition of the overall problem area was needed, it was decided to investigate lateral and tailward acting forces during Phase I. Knowledge concerning the limits for the six major directions, however, is not adequate for the design of an impact attenuating system. Few, if any, of the impact forces will be parallel to one of the six major directions, as can be seen by figures 3 and 4. Furthermore, there are no methods known today for extrapolating with confidence the tolerance data across the intervening 90° angles between the major directions. This lack of confidence does not exist for extrapolating over 45° angles. It was decided, therefore, that in Phase II the eight intermediate directions between forward acting forces and the forces parallel to the coronal plane of man should be investigated (fig. 5). These are the directions most likely to be encountered in a normal ballistic landing vehicle. Phase III would consist of a study of the anterior intermediate forces and any additional intermediate directions considered necessary to investigate as a result of the findings from Phases I and II (fig. 6).

Phase I

To carry out Phase I of the program, four organizations in the Department of Defense were requested to join in a team effort. The four groups were:

The Armed Forces Institute of Pathology, Washington, D. C.

The Air Crew Equipment Laboratory, Naval Air Materiel Center, Philadelphia, Pennsylvania

The 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio

The 6571st Aeromedical Research Laboratory, Holloman Air Force Base, New Mexico.

The Armed Forces Institute of Pathology (AFIP) was requested to survey their autopsy reports and other records available to determine the probable causes for torn or ruptured chest vessels and, if possible, to determine the relationship between the direction of an impact force and the associated injury. In addition, the Aeromedical Research Laboratory (ARL) was requested to verify the AFIP findings by exposing animals to impact forces.

Based on the equipment available, the Aerospace Medical Research Laboratories (AMRL) were requested to investigate lateral impact loads by using their vertical drop tower. The Air Crew Equipment Laboratory (ACEL) was requested to investigate tailward acting impact loads (eyeballs up) by using their horizontal catapult.

During these investigations, the couches and restraint systems used were basically the same to insure the acquisition of data from a common base. The couch, in all cases, was a semicontoured rigid support. Although it was necessary to modify the original model slightly, the restraint systems used by all three investigators were the same in basic principles.

The complete results of Phase I have been reported by the principal investigators from the organizations concerned and will not be repeated in this paper.

Phase II

During Phase II, eight directions in the posterior cone were investigated. Five directions (numbers 3, 4, 5, 6, and 7 of figure 5) were investigated on the vertical drop tower at AMRL. The five directions numbered 1, 2, 3, 7, and 8 on figure 5 were investigated on the Daisy Decelerator at ARL. Directions 3 and 7 were studied on both facilities in order to correlate the data from the two different devices. However, no noticeable differences were uncovered during these tests. The collection of data on this phase of the program is complete and part of the results have been reported; however, because of time limitations, not all of the data have been processed.

RESULTS OF PHASE I AND PHASE II OF IMPACT PROGRAM

As a result of the studies conducted in Phases I and II, it has been possible to establish arbitrary limits for impact forces that the astronauts will be expected to endure during a normal spacecraft mission. The selection

of these limits was based on four main factors. The first consideration is the limits of the variables for a normal mission. In this case, a normal mission is defined as one during which the vertical sink rate of the spacecraft and parachutes does not exceed 30 feet per second, the horizontal wind drift rate does not exceed 34 feet per second, and the spacecraft does not tumble. Second, the arbitrary limits chosen should be low enough to ensure that exposure to impacts of this magnitude will induce little or no evidence of pending physiological problems. Third, the limits selected must be of a magnitude such that there would be no hesitancy in accepting this load routinely during every landing. It should be noted that the Mercury landings (approximately 15g) have not been thought worthy of adverse comment by the astronauts. The fourth, but not the least important, consideration is the unknown effect of prolonged weightlessness; which, when combined with the other physiological stresses, dictates that the limits chosen be somewhat below the magnitudes reached in the impact program.

The selected limits are shown in figure 7. Considering a man in the supine position, the envelope of the acceptable impact forces may be described as a 15g cylinder having a 20g (EBI or $+G_x$) spherical cap. For essentially forward acting forces, the limits are 20g. For lateral, headward, and tailward acting forces, the limits are 15g. Specific rates of onset (rate of application of g) are associated with these limits also. For forward acting forces, the allowable rate of onset is 10,000g per second; for lateral acting forces, 1,000g per second; and for headward and tailward acting forces 500g per second. For the intermediate 45° directions having a forward acting component, the rate of onset may be 1,000g per second also. With these guidelines (fig. 7), an interpolation may be made to find an acceptable limit for any direction within the limits of the figure.

The limits described are valid only for the range of variables indicated. Velocity changes, rise times, and direction of applied forces, must be within the limits indicated. The restraint and support systems must be similar in principle to that shown by figure 8. The head, shoulders, and pelvis must be supported laterally by essentially rigid structure. Comfort layers, one-half inch thick, were found to be detrimental; complete deletion of a comfort layer gave the best results. The depth of the lateral supports in the front-to-back direction should be such that the subject's body cannot roll up and over the sides. The restraint harness should thoroughly restrain the subject's chest, pelvis, and thighs. The relative tensions for lap and shoulder straps for optimum results have not been determined. However, for the limits shown, the shoulder straps should be snug in order to restrain the chest for the directions being discussed and the lap-thigh strap combination should be slightly tighter than the shoulder straps.

SUMMARY

The limits described in the previous paragraph will suffice if the spacecraft does not tumble during the landing. If the vehicle does tumble,

data upon which to base the acceptable limits for impact forces having backward acting (EBO or $-G_x$) components must be obtained. Phase III of the impact program has been initiated to provide such data. This phase of the program, however, will encounter all of the problems associated with producing optimum restraint systems. Past experience has shown that restraint harness problems are usually complex and a particular magnitude of impact force may be quite acceptable with one harness design and completely unacceptable with a design that appears to be only slightly different. The reasons for such differences must be determined. It will then be possible to specify harness arrangements to satisfy specific problems and to select impact limits for the direction not studied in Phases I and II.

TOLERANCE DATA AVAILABLE FOR DIRECTIONS SHOWN

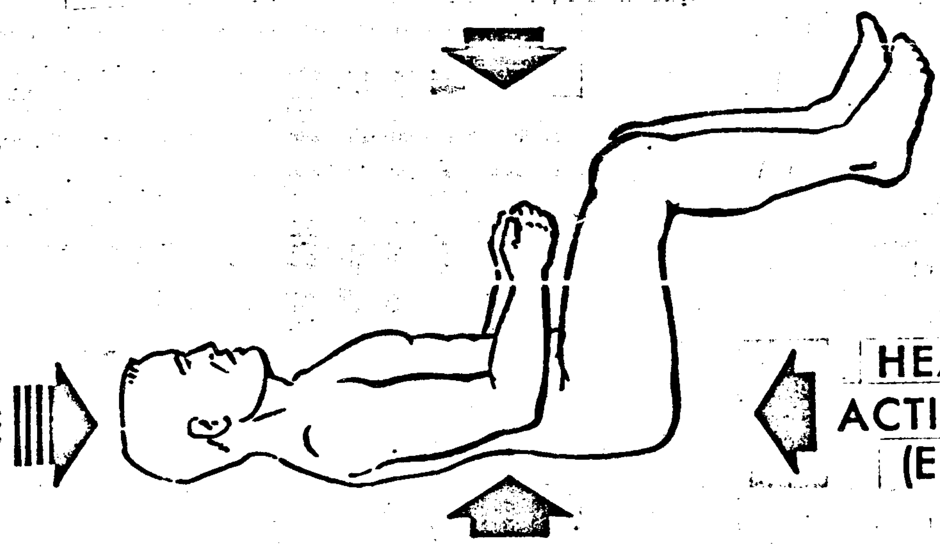

Figure 1

TOLERANCE DATA NOT AVAILABLE

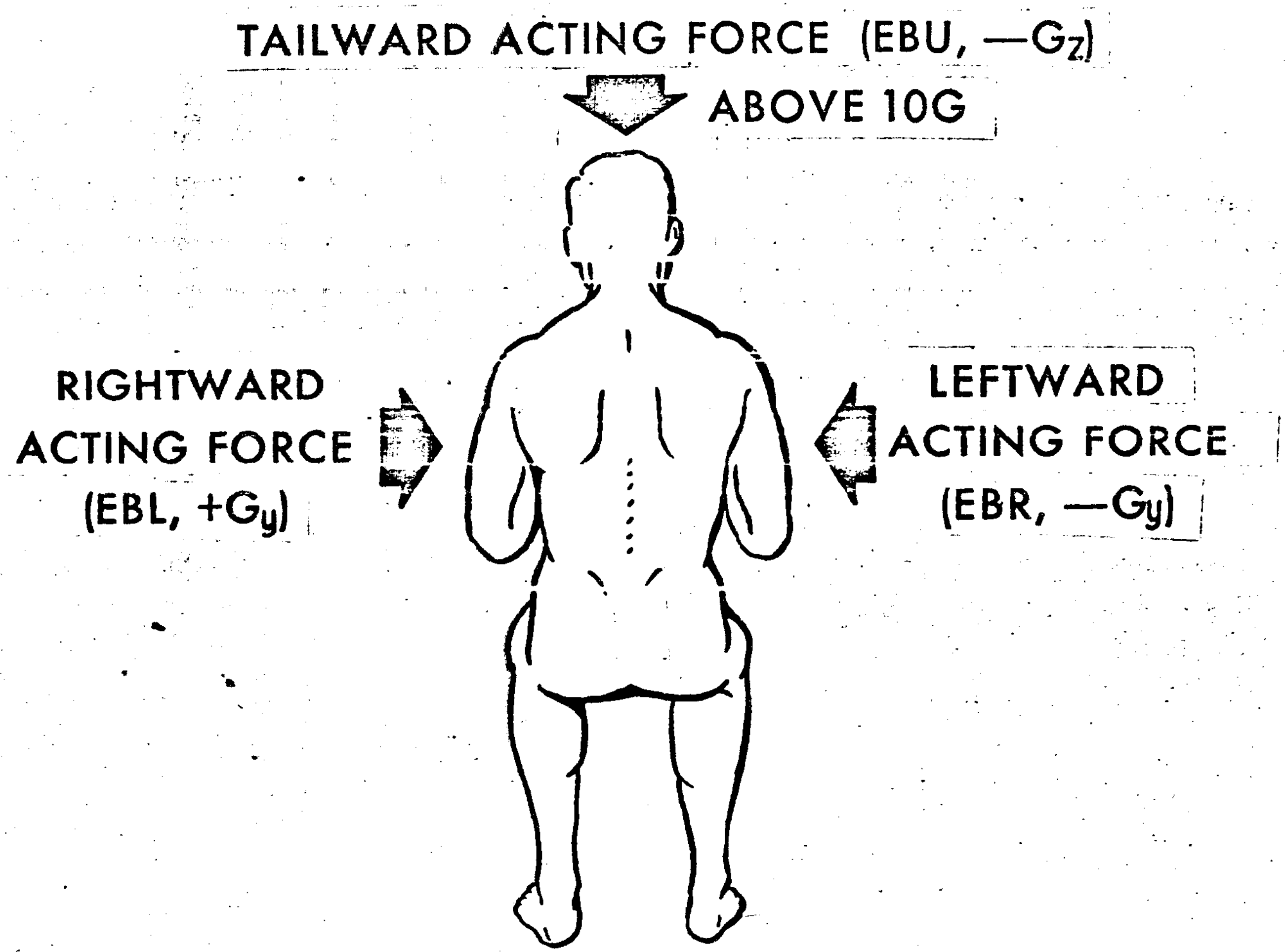

Figure 2.

MOTIONS DURING SPACECRAFT DESCENT

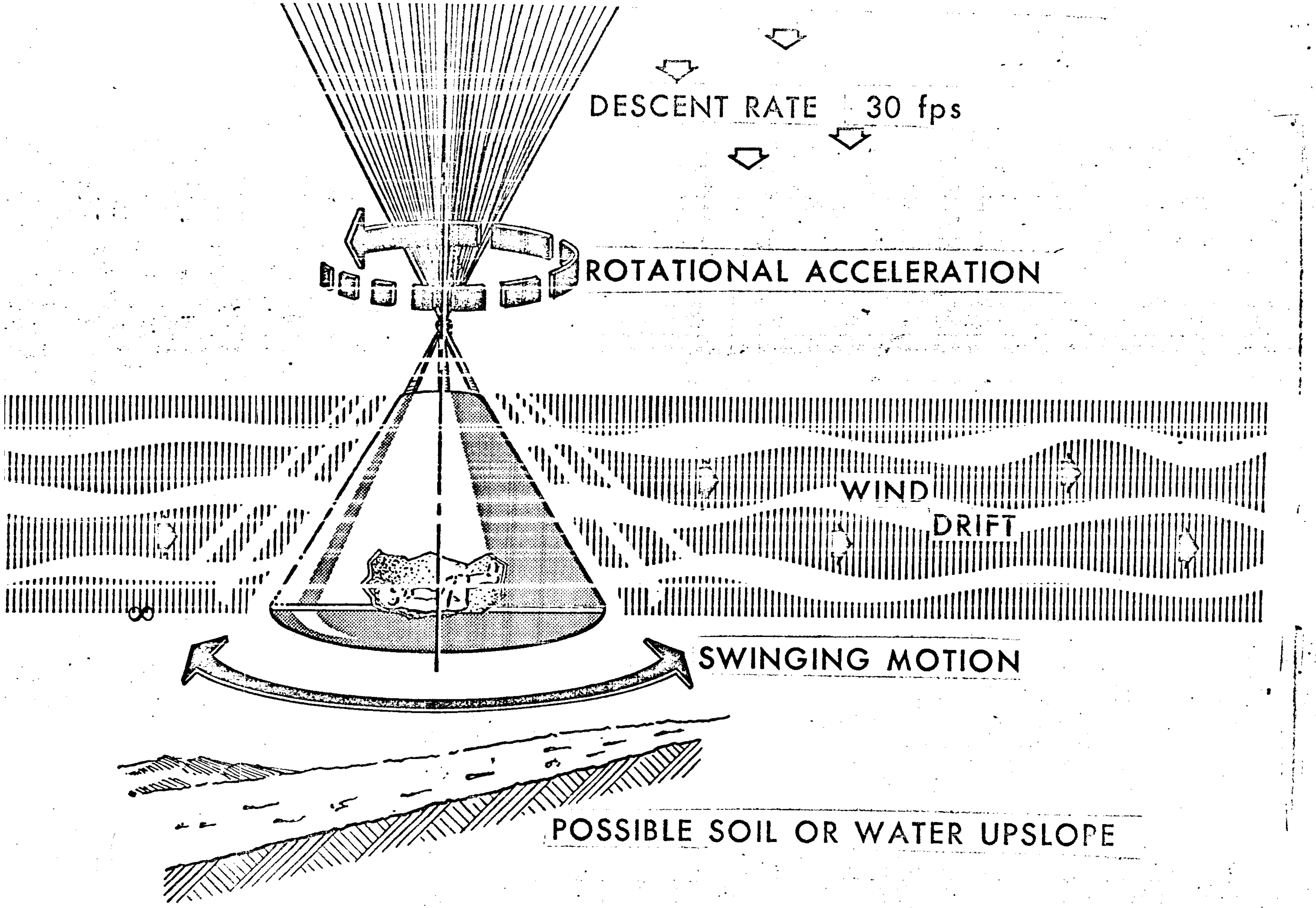

Figure 3

SPACECRAFT LANDING FORCES

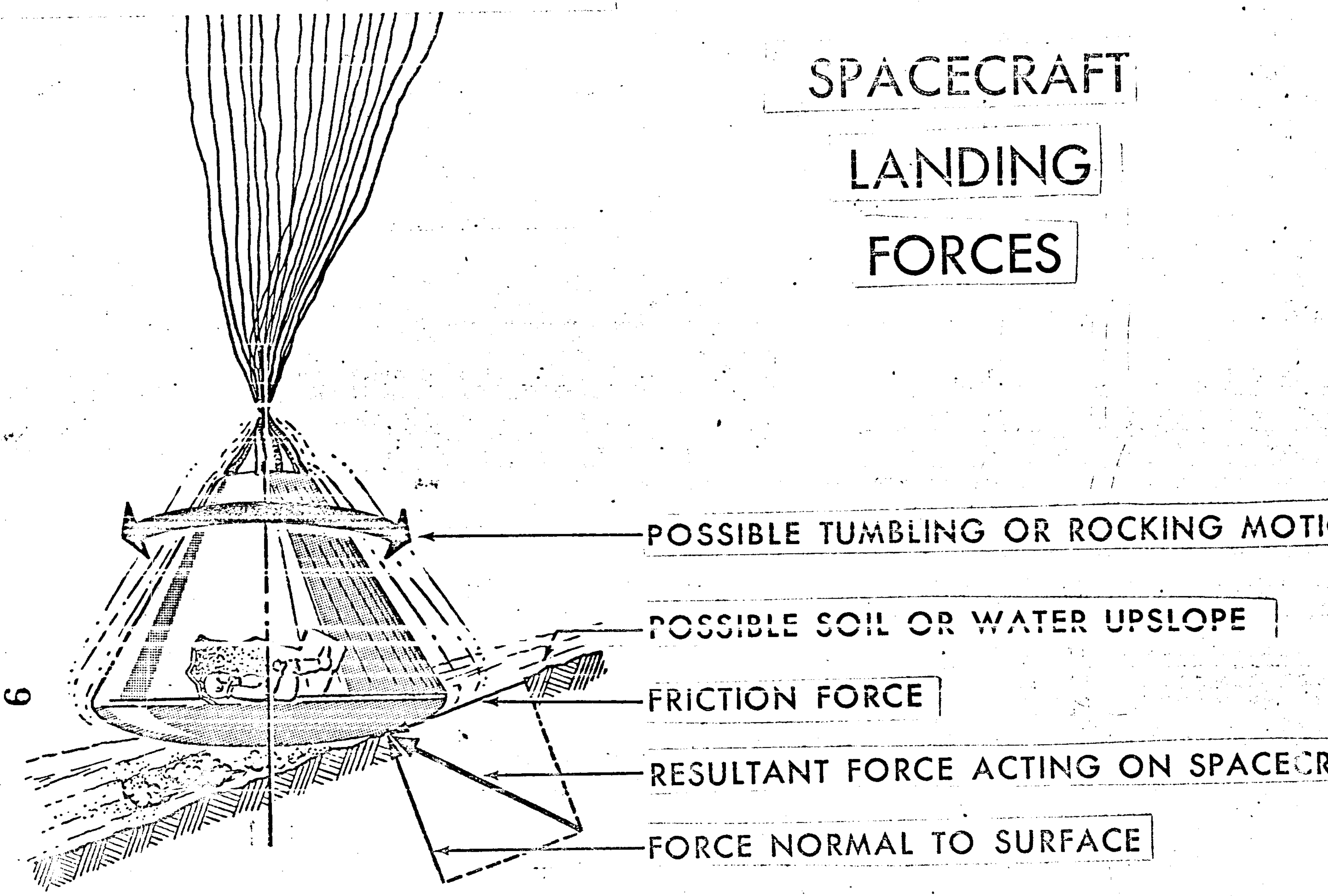

Fig. 4

NASA-MSC G J PESMAN 18 APR 63 S-299-16

DIRECTION OF IMPACT FORCES FROM POSTERIOR 45° CONE

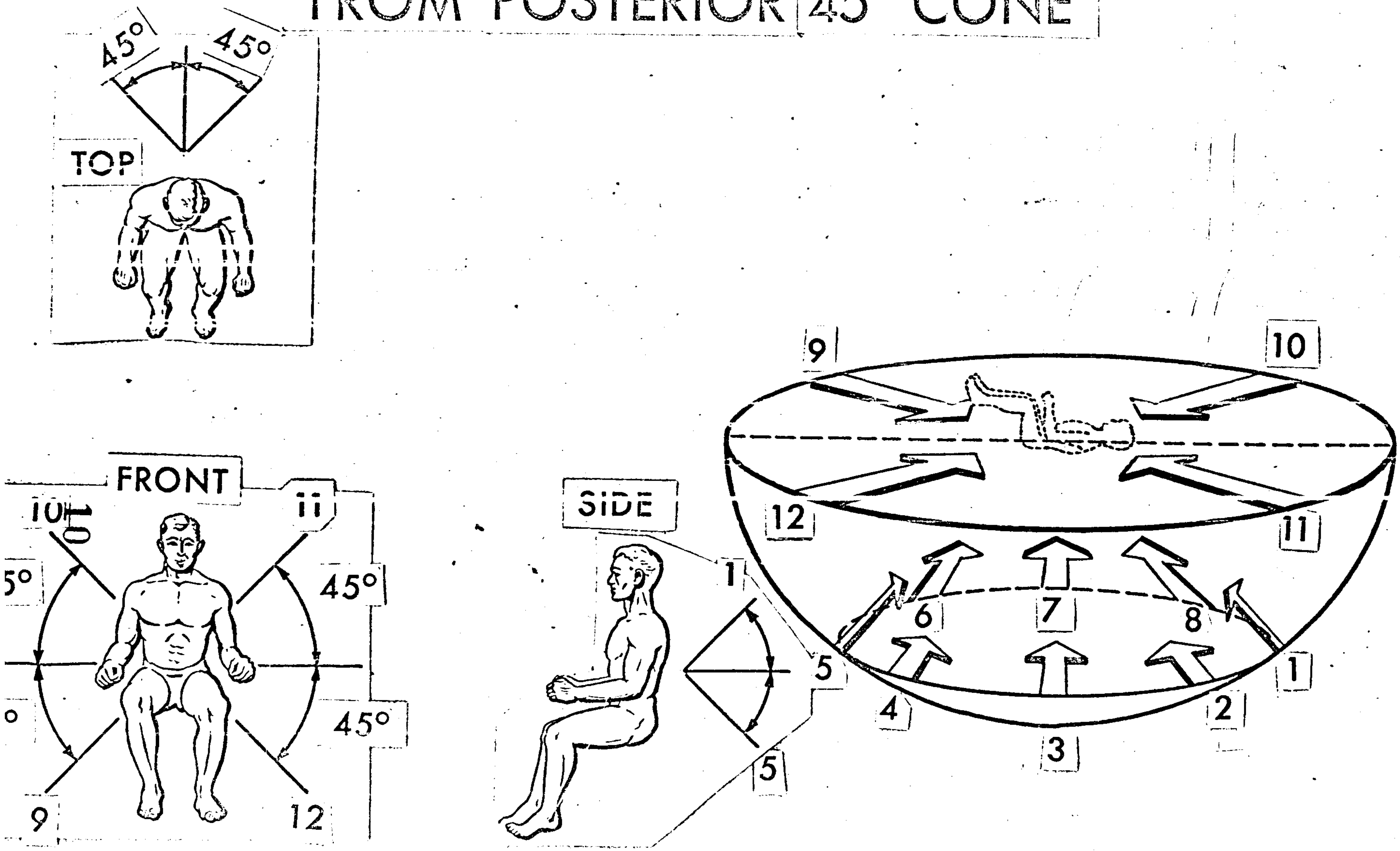

Figure 5

DIRECTION OF IMPACT FORCES FROM ANTERIOR 45° CONE AND CORONAL PLANE

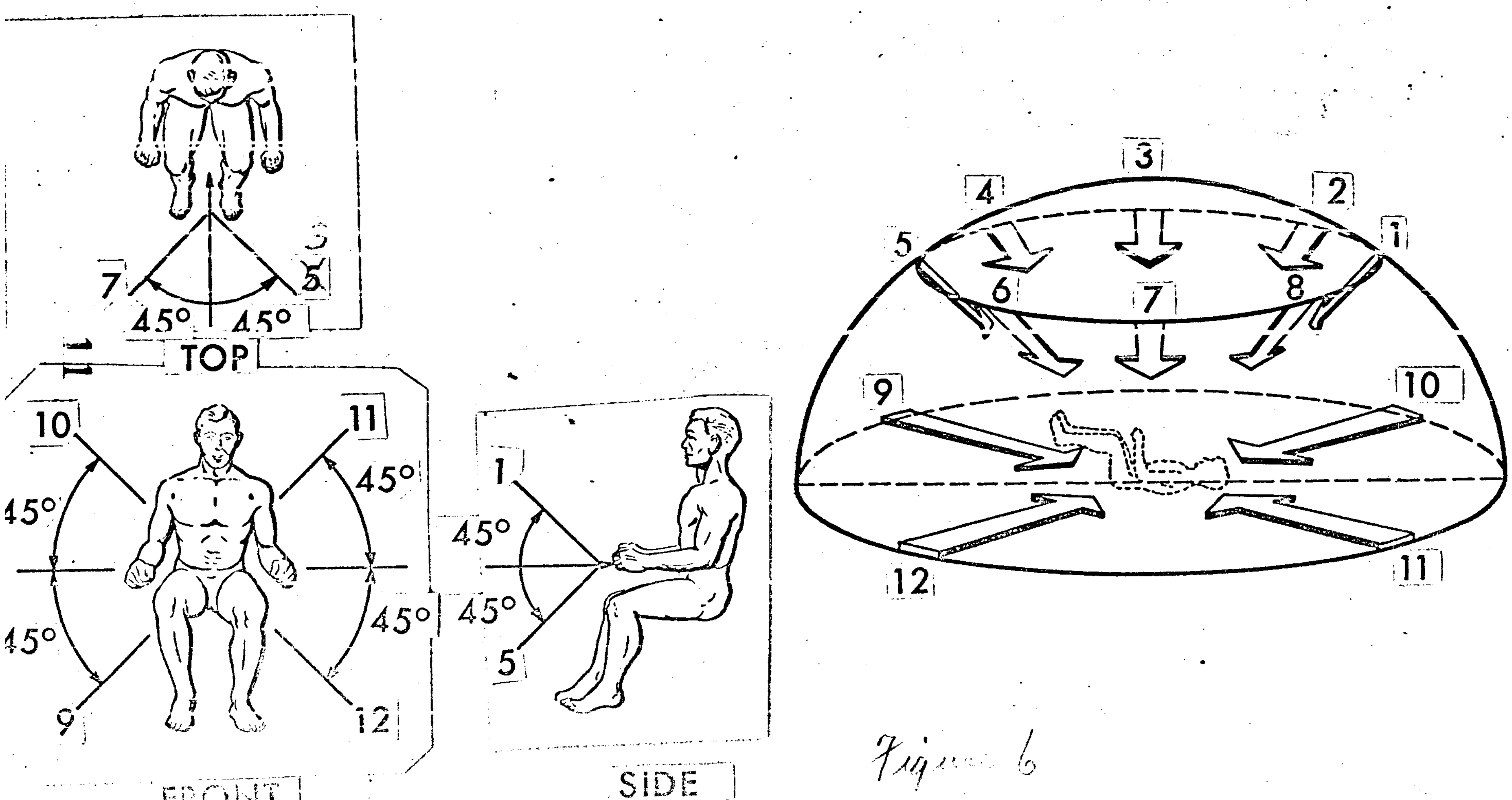

Figure 6

NORMAL MISSION LIMITS

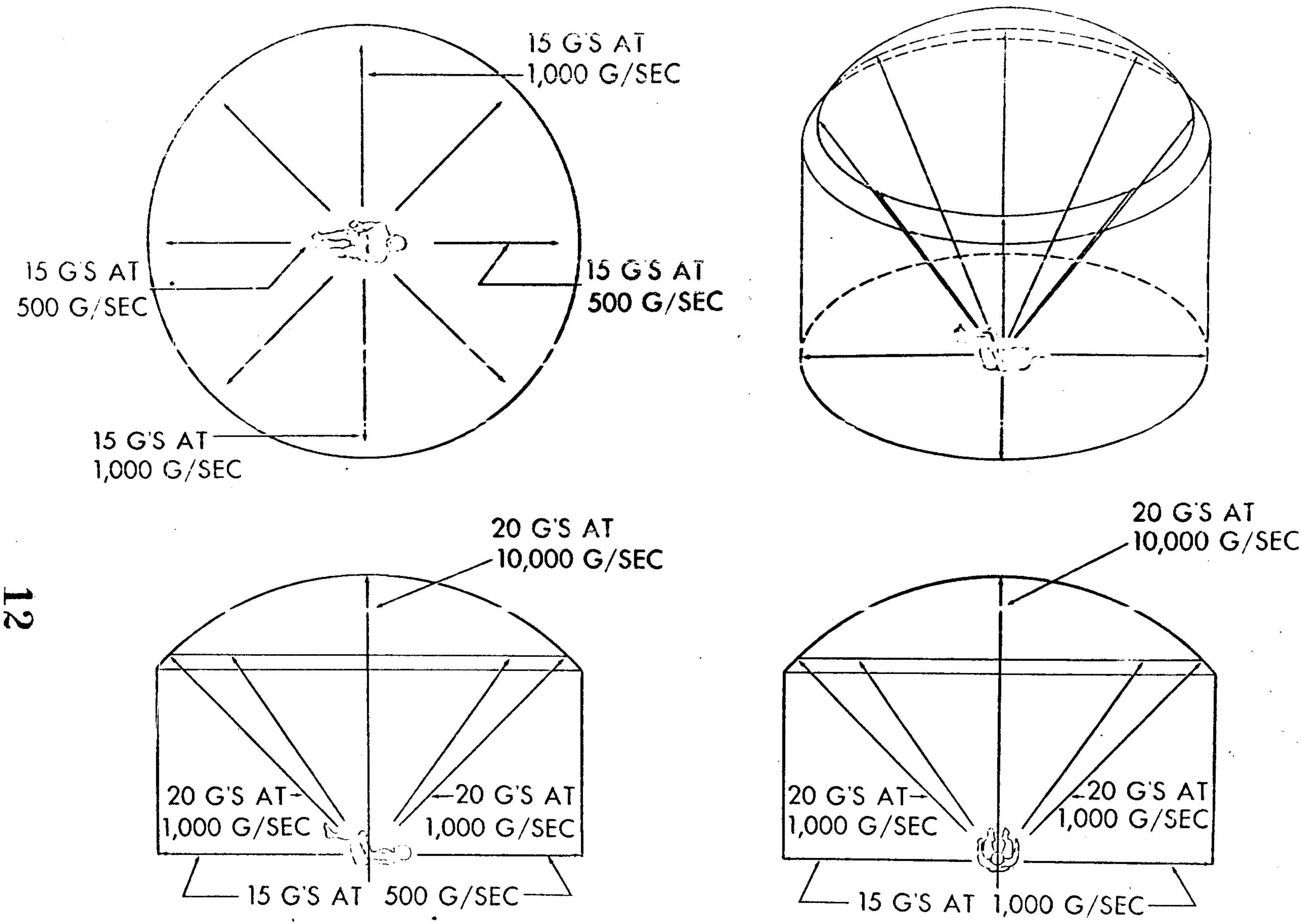

Fig 7

NASA - [illegible] APRIL 11, 1963 S-299-11

See over

Following note to be placed on figure

Note: Limits apply only when velocity change resulting from impact is below 30 fps and when subject is supported and restrained as described in discussion.

ILLUSTRATION OF RESTRAINT & SUPPORT

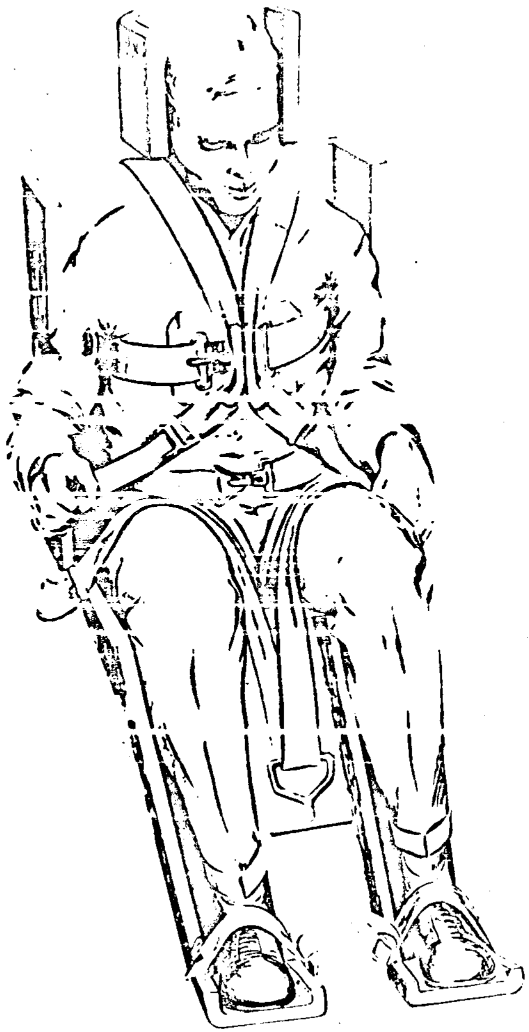

Fig 8

NASA - MSC G. J. PESMAN APRIL 11, 1963 S-299-10